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Effect of Wildfire on Soil Wettability in the High Cascades of Oregon

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EFFECT OF WILDFIRE ON SOIL WETTABILITY IN THE HIGH CASCADES OF OREGON

Reference Abstract

Dyrness, C. T.
1976. Effect of wildfire on soil wettability in the High Cascades of Oregon. USDA For. Serv. Res. Pap. PNW-202, p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Soil wettability characteristics and revegetation trends were studied for 6 years following the 1967 Airstrip Burn, a 7,700-acre (3 116 ha) wildfire which burned in lodgepole pine stands at approximately 5,000-foot (1 524 m) elevation. Wettability of the sand-textured soils was evaluated by liquid-solid contact angle and infiltration rate determinations. Burning apparently increased the water repellency of the soil at depths of 1 to 9 inches (2.5 to 23 cm), which persisted for 5 years after the fire. By the 6th year, contact angle values for both lightly and heavily burned soil were approaching those for the unburned soil. Recovery rates during the 3d and 4th years were more rapid for lightly burned soils than for heavily burned. Two applications of a nonionic wetting agent had almost no detectable effect on soil wettability and rates of revegetation, probably due to rapid downward leaching of the chemical. Yearly vegetation inventories showed a much faster rate of revegetation in lightly burned areas than in heavily burned. Most of the plant species coming in after the fire were present before the burn. Grasses and clover, which were aerially seeded soon after the fire, contributed only negligible amounts of cover.

Keywords: Wildfire (-hydrology, soil condition (-forest damage.

RESEARCH SUMMARY
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This report summarizes results of the first study undertaken in Oregon on the effects of fire on soil wettability. Although it has long been known that wildfire may cause nonwettable soils elsewhere in the West (and especially in southern California), it is only recently that this same problem has been found in Oregon. During late summer of 1967 a wildfire burned over 7,700 acres (3 116 ha) of predominantly lodgepole pine (*Pinus contorta*) at an elevation of about 5,000 feet (1 524 m) in the Willamette National Forest of Oregon. Following the fire it was noted that certain soil layers showed varying degrees of water repellency. While unburned soils showed moderate resistance to wetting in the surface 2 inches (5.1 cm), burned soils were wettable in the surface but were strongly nonwettable at 2 to 6 inches (5.1 to 15.2 cm). This

water repellency was causing increased runoff and erosion. Preliminary analysis indicated these burned soils had a higher degree of water repellency than most nonwettable soils in southern California (DeBano 1969).

In order to explore these relationships more fully, soil wettability characteristics and revegetation trends were studied for 6 years following the 1967 Airstrip Burn. Wettability of the sand-textured soils was evaluated by liquid-soil contact angle and infiltration rate determinations. Results indicated that fire caused increased water repellency in burned soils. Although burned soils were slightly more wettable than unburned soils in the surface inch, substantial increases in water repellency were found for the 1- to 6-inch (2.5- to 15.2-cm) soil depths in burned areas. Decreases in soil wettability persisted in the burned areas for 5 years after the fire. By the 6th year, contact angle values for the burned soil samples were approaching those measured in the unburned soil. Recovery rates during the 3d and 4th years were more rapid for lightly burned soils than for heavily burned.

Vegetation inventories showed a much faster rate of revegetation on lightly burned plots than on the heavily burned. Most species coming into the burned areas were also present before the fire. Grasses and clover which were aerially seeded soon after the burn contributed only negligible amounts of cover.

In 1968 and 1969, the wetting agent Aqua-Gro was applied to half the plots in each condition (unburned, lightly burned, and heavily burned). No effect on plant growth could be determined. Effects of the wetting agent on soil wettability were minimal. Apparently nonionic surfactants offer little promise as a practical method for ameliorating the detrimental soil effects of burning, at least in areas receiving sufficient precipitation to leach them from the soil profile.

Wildfires in areas of sandy soils on steep slopes could lead to serious erosion problems caused, in large part, by decreased soil wettability. Since decreased soil wettability persists for several years, it is essential that the land manager act immediately to aid soil stabilization as soon as the fire is controlled. Probably the most effective treatment would be immediate seeding of well-adapted grass and legume species and the liberal application of a nitrogen fertilizer.

INTRODUCTION

Nonwettable soils have been studied most intensively in the San Gabriel Mountains of southern California. Following a 1962 fire adjacent to the San Dimas Experimental Forest, the surface soil over much of the burned area was found to exhibit marked nonwettable properties (Osborn et al. 1964, Krammes and DeBano 1965). After rainstorms, it was noted that although the surface inch or two of soil was saturated, the layer immediately below was generally comprised of air-dry soil. Subsequent research has indicated that due to decreased infiltration rates, soil erosion during rainstorms is considerably greater in areas of nonwettable soils (Osborn et al. 1964, DeBano et al. 1967).

The agent responsible for the formation of nonwettable soils in southern California appears to be organic substances produced by shrub species. Letey et al. (1962) demonstrated that extracts of chaparral litter can produce nonwettability in previously wettable sands. DeBano (1966) suggested that the formation of a nonwettable soil layer may be the result of a hydrophobic organic compound volatilizing due to the heat of the fire and later condensing on cooler soil particles. More recent work by Savage et al. (1972) demonstrated that water repellency of burned soils was the result of heating of surface litter. The effective water-repellent substances were collected and identified as aliphatic hydrocarbonlike materials.

The application of wetting agents appears to offer some promise for ameliorating the effects of soil nonwettability. Early plot experiments in southern California demonstrated reduced erosion and improved establishment of vegetation as a result of the application of wetting agents (Osborn et al. 1964, Krammes and Osborn 1969). However, aerial application of a wetting agent to an entire burned-over watershed near Glendora, California, had no effect in decreasing soil erosion (Rice and Osborn 1970). Thus, the usefulness of large-scale applications of wetting agents to forest soils on an operational basis is not yet demonstrated.

Recently it has become increasingly apparent that resistance to soil wetting is a widespread phenomenon in the Western United States, especially following fire. DeBano (1969a) reported that, in addition to California, water-repellent soils have been observed in Oregon, Idaho, Montana, Nevada, Utah, Colorado, Arizona, and New Mexico. The study reported here was conducted in an area where water repellency was more severe than has been reported for any other area within the Western United States (DeBano 1969a, 1969b).

During late August and early September of 1967, a wildfire swept through 7,700 acres (3 116 ha) of predominantly lodgepole pine (*Pinus contorta* Dougl.) forest land in the Willamette National Forest of Oregon. During the first fall rains after the fire, it was noted that considerable runoff and erosion were occurring due to decreased infiltration rates. Further investigation disclosed that certain soil layers were exhibiting varying degrees of water repellency. In lightly burned areas, the soil at a depth of 1 to 3 inches (2.5 to 7.6 cm) showed strong nonwettable properties, while at 3 to 6 inches (7.6 to 15.2 cm) the soil was moderately resistant to wetting. Severely burned soils tended to be wettable from 0 to 3 inches (0 to 7.6 cm) and nonwettable at 3 to 6 inches (7.6 to 15.2 cm). At the same time, unburned soils exhibited moderate resistance to wetting in the surface 2 inches (5.1 cm), with wettable soil beneath.

In order to investigate the effects of burning on soil wettability in more detail, an exploratory study was begun during the

summer following the fire (1968). The study had two main objectives: (1) to determine the effects of burning on soil wettability and to discover how long such effects persist, and (2) to determine the effect of the application of a wetting agent on soil wettability and revegetation.

STUDY AREA

The study was conducted in the 7,700-acre (3 116 ha) Airstrip Burn on the crest of the Cascade Range near Santiam Pass, Willamette National Forest. The fire occurred during the period of August 28 until September 8, 1967. The pattern of burning included several areas of very severe burn, some light burn with only partially killed tree crowns, and some completely unburned islands.

Vegetation before the fire consisted of a rather open pole-size stand predominantly of lodgepole pine with varying amounts of subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*).[1/] Understory vegetation was fairly scattered, with perhaps a maximum of 40- to 45-percent total cover. The most abundant species were sickle-keeled lupine (*Lupinus albicaulis*) and long-stoloned sedge (*Carex pensylvanica*). Species contributing smaller amounts of cover included the grasses western stipa (*Stipa occidentalis*) and bottle-brush squirrel-tail (*Sitanion hystrix*), and squaw currant (*Ribes cereum*) and Bloomer's haplopappus (*Haplopappus bloomeri*).

The study area is situated within the High Cascades geologic province. Bedrock in the area is made up of basalts and andesites laid down during the Pleistocene. The bedrock is overlain by deep, relatively recent deposits of vocanic ash, cinders, and pumice. The principal soil in the area is a poorly developed Vitrandept, exhibiting 2-inch (5.1 cm) A1 and 10- to 12-inch (25.4- to 30.5-cm) AC horizons. Soil textures are coarse--ranging from a loamy sand to a sandy loam. Slopes are gentle within the burn, except for several isolated buttes and volcanic cones. Elevations range from about 4,640 to 5,460 feet (1 414 to 1 664 m) above sea level. The area is characterized by dry summers and an annual precipitation of about 95 inches (2 413 mm), much of which is snow.

Following the fire (October 1967), the area was aerially seeded with grass, clover, and tree seed. Species seeded included tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), lodgepole pine, ponderosa pine (*Pinus ponderosa*), and western white pine (*Pinus monticola*).

STUDY METHODS

Vegetative cover was estimated in early September of each year (1968 through 1973) on milacre plots. These plots were square (6.6 feet (2 m) on a side), with one-quarter of the large plot subdivided into nine subplots, each 1.1 foot (0.34 m) square. Cover of shrub and tree species was estimated on the large plot and herbaceous cover, on the nine subplots. Ten sets of paired plots were located at 50-foot (15.2-m) intervals along transects in each of three areas--heavily burned, lightly burned, and unburned. Thus there were 20 plots in each condition for a grand total of 60 plots. One plot of each pair remained untreated, while the other plot was treated with a wetting agent.

Of 10 plot pairs in each condition, 2 pairs (4 plots) were randomly selected as soil sample plots. Here soil wettability samples were collected and infiltration tests made each time the vegetation was inventoried (early September of each year).

[1/] Plant names are from Franklin and Dyrness (1973).

Soil samples were collected from the following depths:

- 0- to 1-inch (0- to 2.5-cm)
- 1- to 2-inch (2.5- to 5.1-cm)
- 2- to 4-inch (5.1- to 10.2-cm)
- 4- to 6-inch (10.2- to 15.2-cm)
- 6- to 9-inch (15.2- to 22.9-cm)
- 9- to 12-inch (22.9- to 30.5-cm).

In 1968, one set of samples was collected from each sample plot. However, in 1969 through 1973, two sets of soil wettability samples were collected at each soil sample plot, for a total of 144 per year. Infiltration capacity was estimated each year using ring infiltrometers 6 inches (15.2 cm) in diameter. The time necessary for the infiltration of 3 inches (76.2 mm) of water was determined at three locations per plot.

In August of 1968 and June of 1969, one plot of each pair was treated with the wetting agent Aqua-Gro,[2/] a nonionic surfactant. In 1968, the wetting agent was applied at the manufacturer's recommended rate, which totaled 35 milliliters of Aqua-Gro per plot. The rate was doubled to 70 milliliters per plot in 1969. For each treated plot the Aqua-Gro was mixed with 7.5 liters (2 gallons) of water and applied by sprinkling it onto the plot surface.

Soil samples were air dried soon after they were brought into the laboratory. Samples were then placed in petri dishes and relative wettability determined by the water drop test. Several drops of water were placed on each soil sample, and the length of time necessary for the water to soak into the soil was measured.

Liquid-solid contact angles were also determined for all samples, using the method suggested by Letey et al. (1962). This is a capillary rise technique which involves measuring height of rise in soil columns placed in water and in ethanol. Air-dried soil was packed to an equal density in two glass tubes 8-9 millimeters in diameter. These were held vertical for 24 hours, with the lower end of one column immersed in water and the other in ethanol. The heights of the wetting fronts were then measured. The liquid-solid contact angle was calculated from:

$$\text{Cos angle} = 0.3961 \frac{\text{height water}}{\text{height ethanol}}.$$

Results of contact angle determinations were analyzed by a single analysis of variance. In this analysis, the 1968 data were omitted because the wetting agent treatment was not complete until 1969. This approach to statistical analysis is relatively complex because of the four variables involved--burning treatment, wetting agent treatment, soil depth, and year. However, the single analysis alternative was adopted as offering the most effective means of exploring possible interactions among variables.

RESULTS

SOIL WETTABILITY

Drop tests as a means of assessing soil wettability gave somewhat unsatisfactory results. We found it extremely difficult to obtain reproducible time readings, probably due to combined effects of variation within a soil sample and the difficulty of subjectively determining when a water drop had actually soaked into the soil. It became especially difficult after 2 hours to distinguish between absorption and evaporation. Consequently, all readings of 2 hours and longer were arbitrarily assigned to a "water drop evaporated" category.

[2/] Supplied in liquid form by Aquatrols Corporation of America, Camden, N.J. Trade names and commercial products or enterprises are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Correlation between water drop results and liquid-solid contact angle determinations were generally poor. The erratic nature of drop test results is shown in figure 1. Despite some initial difficulties in obtaining consistent, reproducible contact angle data (largely due to a lack of uniformity in soil density in the glass tubes), contact angle results appear much more reliable and consistent than do drop test results. Consequently, discussion of changes in soil wettability will be based exclusively on liquid-solid contact angle data. Resistance to wetting is directly proportional to the magnitude of the liquid-solid contact angle. Thus, contact angles greater than 80 degrees indicate extreme resistance to wetting, and those in the 70-degree range represent at least moderate resistance to wetting.

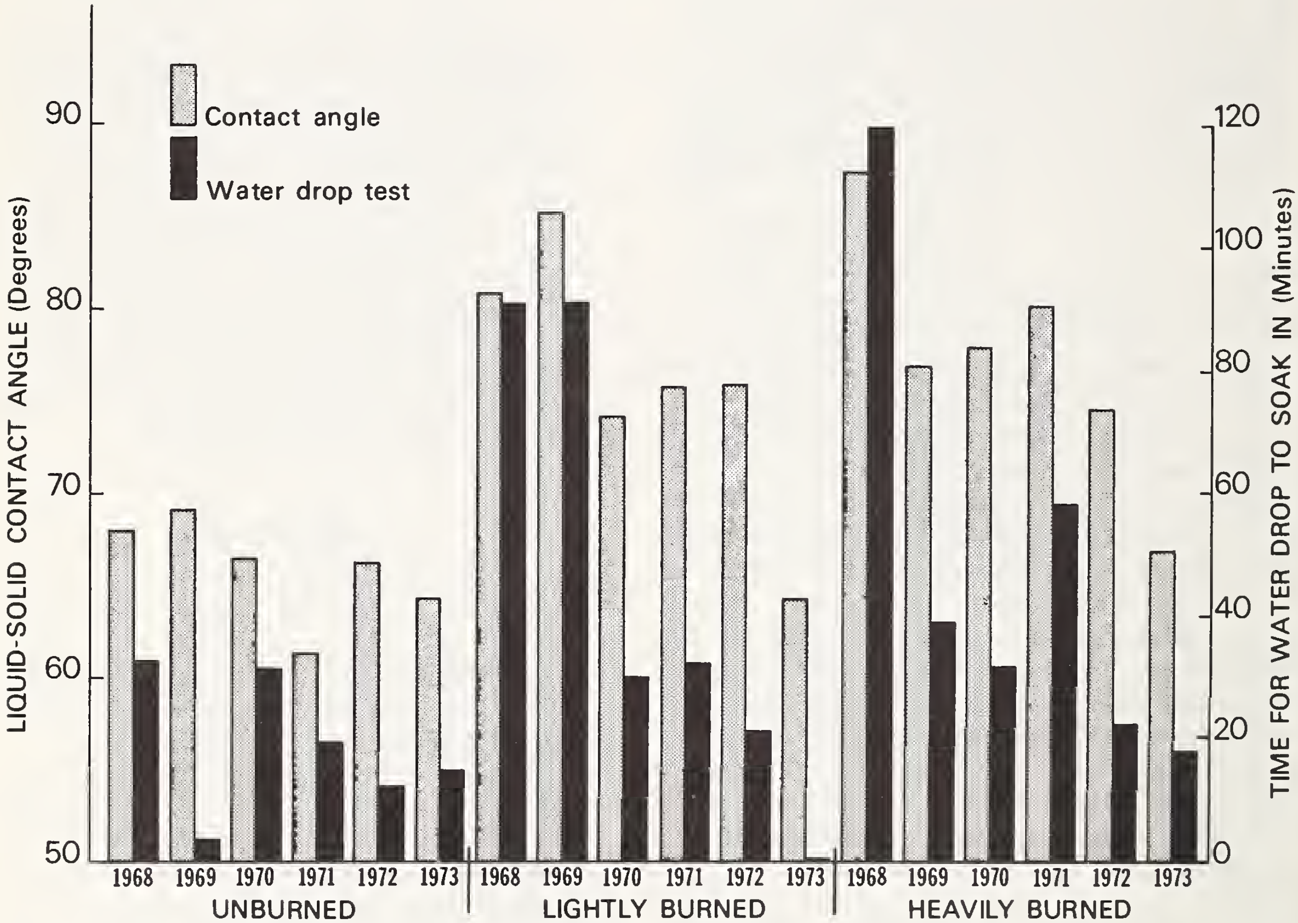

Figure 1.--Liquid-solid contact angles and water drop test results for the 1- to 2-inch (2.5- to 5.1-cm) soil depth in heavily burned, lightly burned, and unburned areas for 6 years after burning. Each value represents the mean of eight measurements, except for 1968 where each value represents four measurements.

Results of analysis of variance for the liquid-solid contact angle data are presented in table 1. Despite the fact that effect of burning is nonsignificant, burning has apparently caused some decrease in soil wettability, especially at the 1- to 6-inch (2.5- to 15.2-cm) depths (fig. 2). This is also shown in table 2, where the overall, 5-year contact angle means are 65.61, 71.09, and 75.02 degrees, respectively, for unburned, lightly burned, and heavily burned areas. The lack of statistical significance for an overall burning treatment effect was probably caused by the combined masking effects of the other three variables--wetting agent treatment, soil depth, and years.

Although the effect of soil depth alone is nonsignificant, there is a highly significant soil depth X burning treatment interaction (table 1). The nature of this interaction is illustrated in table 2. Apart from an appreciably higher value in the 0- to 1-inch (0- to 2.5-cm) soil layer, contact angle values remain approximately constant at all depths for the unburned soil. However, in the burned soils, and especially the heavily burned, there is considerable variation in contact angle with soil depth. Here the general pattern is a lower contact angle in the surface inch, an abrupt increase in the 1- to 4-inch (2.5- to 10.2-cm) layers, followed by a gradual decrease in angles with depth. These relationships are shown in figure 2.

Table 1--*Analysis of variance for liquid-solid contact angles for samples collected for 5 years (1969-73) after a wildfire*

Source of variation	Symbols	d.f.	SS	MS	F
Total		359	27,307		
Burning treatment (unburned, lightly burned, heavily burned)	E	2	5,351	2,676	2.41
Error (a)	A + AE	3	3,327	1,109	
Wetting agent treatment (treated, untreated)	B	1	22	22	.05
Wet X burn	BE	2	133	66	.16
Error (b)	AB + ABE	3	1,225	408	
Soil depth sampled (0-1, 1-2, 2-4, 4-6, 6-9, and 9-12 inches)	C	5	402	80	1.33
Depth X burn	CE	10	3,100	310	5.08**
Depth X wet	BC	5	604	121	1.98
Triple interaction	BCE	10	244	24	
Error (c)	AC + ACE + ABC + ABCE	30	1,819	61	
Years (1969, 1970, 1971, 1972, 1973)	D	4	2,944	736	32.00**
Years X burn	DE	8	1,342	168	7.30**
Years X wet	BD	4	325	81	3.52**
Triple interaction	BCD + BDE + CDE	68	1,464	22	
Quad interaction	BCDE	40	853	21	
Error (d)	AD + ABD + ACD + ADE + ABCD + ABDE + ACDE + ABCDE	144	3,350	23	

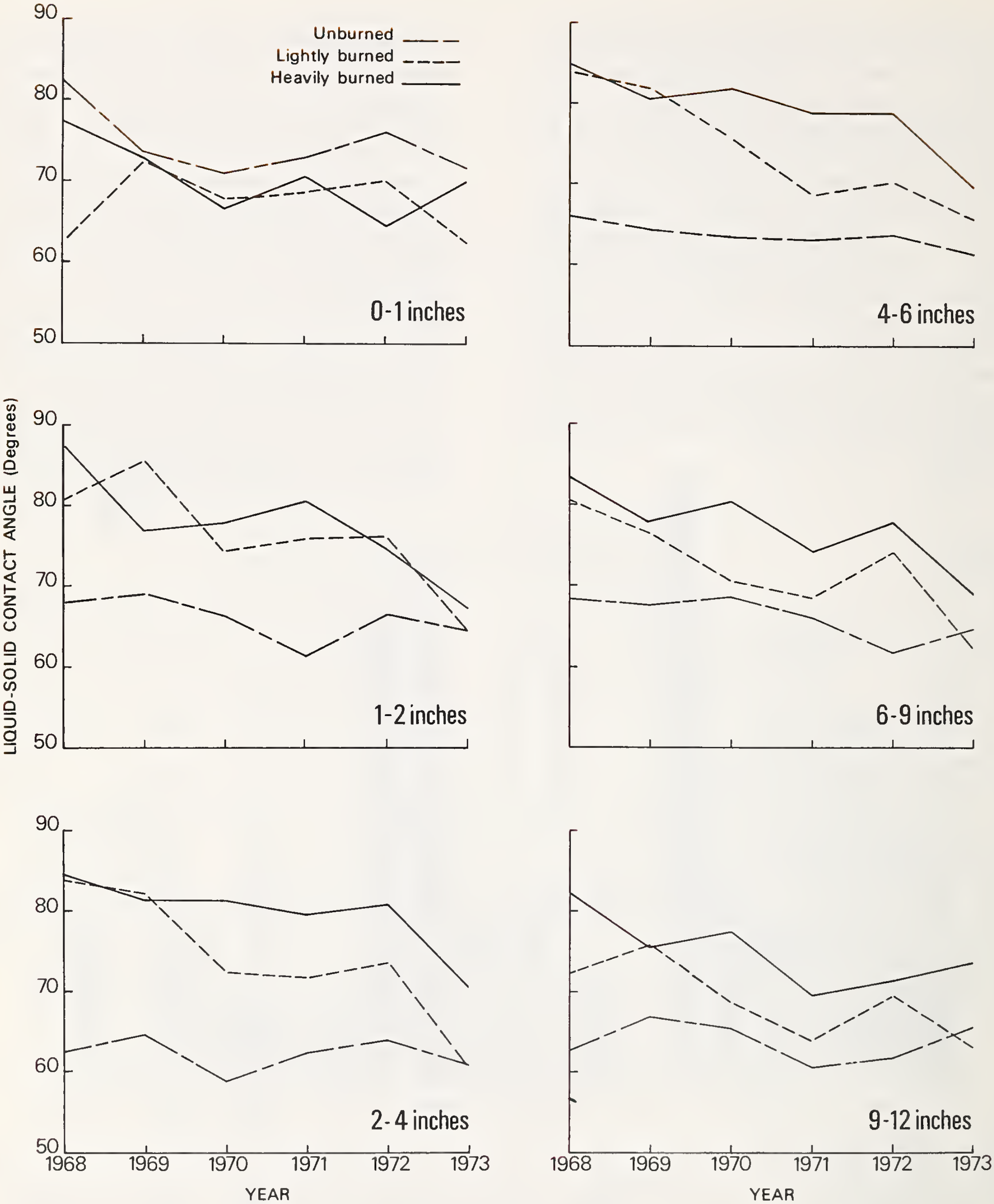

Figure 2.--Mean liquid-solid contact angle values for samples collected at six soil depth intervals in heavily burned, lightly burned, and unburned areas during the first 6 years after the fire. Each value represents the mean of eight measurements, except for 1968 where each value represents four measurements.

Table 2--*Means of liquid-solid contact angles by soil depth and burning treatment. Data for all years (1969-73) and wetting agent treatments (treated and untreated) are pooled*

Soil condition	Soil depth (inches)						
	0-1	1-2	2-4	4-6	6-9	9-12	Mean
	Degrees						
Unburned	73.16	65.38	62.14	63.23	65.76	64.01	65.61
Lightly burned	68.31	75.22	72.12	72.28	70.34	68.24	71.09
Heavily burned	68.87	75.46	78.62	77.86	75.77	73.52	75.02
Mean	70.11	72.02	70.96	71.12	70.62	68.59	70.57

Relationships among soil depth, burning effects, and soil wettability may be summarized as follows: In the surface inch of soil, resistance to wetting was apparently slightly greater in the unburned control than in areas subjected to burning (table 2, fig. 2). At the 1- to 2-inch (2.5- to 5.1-cm) depth the relationship was reversed, with the burned soils definitely showing a greater resistance to wetting than the unburned. This general relationship also held for the 2- to 4- and 4- to 6-inch (5.1- to 10.2-cm and 10.2- to 15.2-cm) depth intervals where the burned soils were clearly more resistant to wetting (table 2, fig. 2). At 6 to 9 and 9 to 12 inches (15.2 to 22.9 and 22.9 to 30.5 cm), differences among burning treatments were smaller; although here, too, the burned soils appear to be more resistant to wetting than the unburned. In every case, the relationship between lightly burned and heavily burned soils was as would be expected; i.e., the heavily burned soil showed more resistance to wetting than the lightly burned (table 2, fig. 2).

How long do these effects on soil wettability persist? This question is at least partially answered by a consideration of analysis of variance results (table 1). These results indicate a highly significant year effect. Although there is very little year-to-year change in liquid-solid contact angles of the unburned soil, values for the burned soil show a general downward trend and a very marked decrease in 1973 (table 3). The absence of year-to-year change in unburned soil probably explains the significant year X burning treatment interaction shown in table 1.

Both the mean contact angle curves in figure 2 and the data presented in table 3 indicate that by the 6th year after burning (1973), differences among treatments had become relatively small. As might be expected, there is some indication that decreased soil wettability may be more persistent in heavily burned soils than in soils subjected to more moderate burning (fig. 2). Note especially trends for the 2- to 4- and 4- to 6-inch (5.1- to 10.2- and 10.2- to 15.2-cm) depths. Here mean contact angle values for the heavily and lightly burned classes were almost identical for the first 2 years after burning (1968 and 1969). However, during the next 2 years, values for the lightly burned treatment

Table 3--*Means of liquid-solid contact angles by year and burning treatment. Data for all six soil depth intervals and wetting agent treatments (treated and untreated) are pooled*

Soil condition	1969	1970	1971	1972	1973	Means
	- - - - - - - - - - - - - - *Degrees*	- - - - - - - - - - - - - - - - -				
Unburned	67.62	65.61	64.38	65.68	64.77	65.61
Lightly burned	79.04	71.58	69.58	72.25	62.98	71.09
Heavily burned	77.46	77.55	75.54	74.65	69.86	75.02
Mean	74.71	71.58	69.83	70.86	65.87	70.57

decreased markedly while contact angles for heavily burned soils decreased only slightly. In these layers, there was not a marked decrease in contact angles for samples from the heavily burned area until 1973 when, in both cases, mean values dropped almost 10 degrees.

Application of the wetting agent, Aqua-Gro, on half the plots in August of 1968 and again in 1969 had little discernible effect on soil wettability as evaluated by liquid-solid contact angle measurements. Neither the wetting agent treatment effect nor the wetting agent X burning treatment interaction was statistically significant (tables 1 and 4). The only significant relationship involving the wetting agent treatment was the wetting agent X year interaction (table 1). An examination of the means (table 5) shows that although mean angles were slightly higher for untreated soils in 1969 and 1970, this difference had disappeared by 1971. Thus, there is some indication that there may be a slight positive effect as a result of wetting agent application which persists for only a brief time. As a result, apparent wetting agent effects are most noticeable in results for samples collected in 1969, approximately 1-1/2 months after the heaviest application of Aqua-Gro. As shown in figure 3, the wetting agent apparently had the greatest effect on the unburned soils and had relatively little effect on burned plots except in the 1- to 2-inch (2.5- to 5.1-cm) heavily burned layer.

INFILTRATION

Measured infiltration rates indicated that soils in unburned areas absorbed water at a rate which was roughly three times faster than soils in burned areas (fig. 4). For example, 1 year after the fire (1968) the average infiltration rate for unburned soils was about 37 inches (940 mm) per hour compared with 14 and 7 inches (356 and 178 mm) per hour for heavily and lightly burned soils, respectively. Despite apparent increases in soil wettability, especially in 1972 and 1973, recovery in infiltration rates was not pronounced (fig. 4). However, there was a gradual increase in infiltration rate on lightly burned plots over the 6-year period--from 7 inches (178 mm) per hour the 1st year after burning to over 13 inches (330 mm) per hour 6 years after burning. Infiltration rates in heavily burned areas were more erratic, with highest rates measured the 1st year after burning.

Table 4--*Means of liquid-solid contact angles by burning treatment and wetting agent treatment. Data for all years (1969-73) and at all six soil depths are pooled*

Soil condition	Treated with wetting agent	Untreated	Mean
	- - - - - - - - - - - *Degrees* - - - - - - - - - - -		
Unburned	69.30	61.92	65.61
Lightly burned	67.76	74.41	71.09
Heavily burned	76.76	73.27	75.02
Mean	70.32	70.82	70.57

Table 5--*Means of liquid-solid contact angles by year and wetting agent treatment. Data for all six soil depths and three burning treatments (unburned, lightly burned, and heavily burned) are pooled*

Treatment	1969	1970	1971	1972	1973	Mean
	- - - - - - - - - - - - - *Degrees* - - - - - - - - - - - - -					
Untreated	76.19	72.51	69.92	69.53	65.95	70.82
Treated with wetting agent	73.23	70.65	69.75	72.19	65.79	70.32
Mean	74.71	71.58	69.83	70.86	65.87	70.57

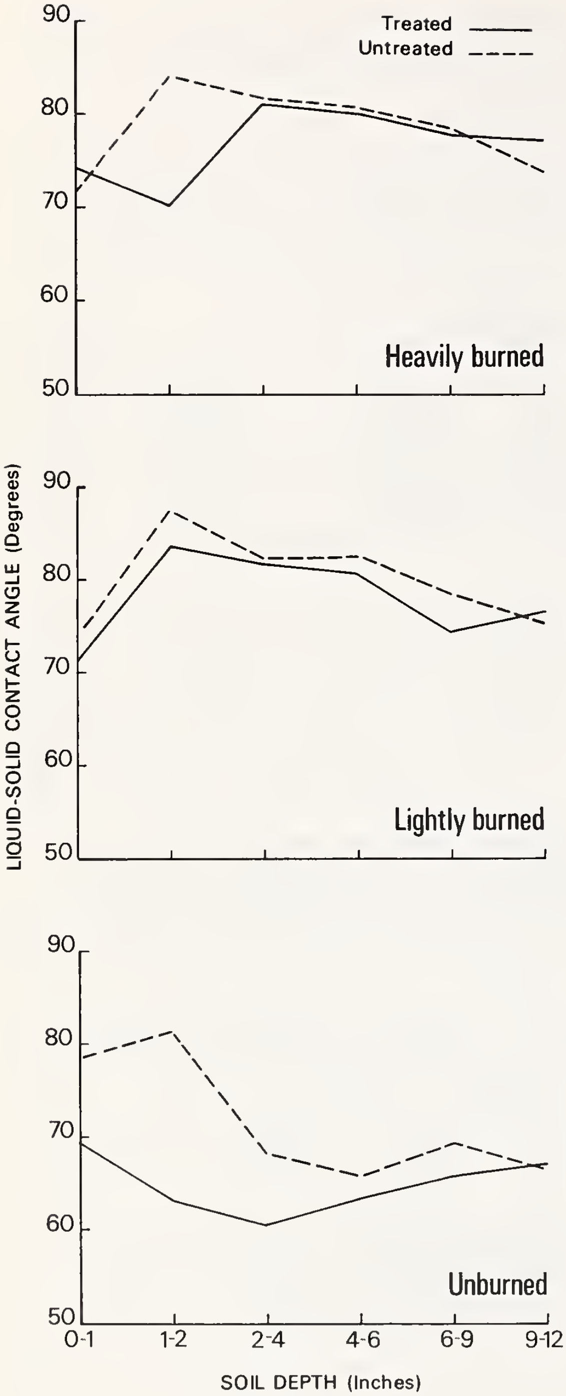

Figure 3.--Mean liquid-solid contact angles for soil samples collected in September 1969 at six depth intervals in lightly burned, heavily burned, and unburned areas. Half the plots were treated with a wetting agent in June 1969. Each value represents the mean of four measurements.

Application of the wetting agent may have had some effect in increasing infiltration rates during the first 3 years after burning. Rates for treated soils were approximately 24 percent higher than those for untreated soils during this period (fig. 4). However, variation among individual measurements was high, making it impossible to state that these differences, from a statistical viewpoint, are real rather than coincidental. During the final 3 years of measurement, wetting agent application apparently had little residual effect--mean untreated infiltration rates were higher than treated rates in five of nine comparisons (fig. 4).

Wetting patterns in the dry soil following early fall rains indicate why infiltration rates were low in burned areas and also explain the substantial variation among measurements. In September of 1969, the first fall rains after the summer dry period produced a highly variable pattern of soil wetting (figure 5). In general, the rain, which had totaled approximately 1.4 inches (36 mm) at the time of observation, had saturated only 1 or 2 inches of the surface soil. This saturated zone was most often underlain by a layer of dry soil ranging from 3 to 9 inches (7.6 to 22.9 cm) thick which was, in turn, situated on top of wet soil. It was obvious that the lower boundary of the dry soil layer constituted a wetting front which was gradually moving upward by capillarity. Closer inspection revealed scattered points at which the lower wet zone was supplied water via old root channels or soil which for some reason was not as water repellent. Once this downward percolating water reached the lower, less water-repellent portions of the profile, it would then spread out and begin its slow capillary ascent into those layers (about 2 to 9 inches (5.1 to 22.9 cm) in depth) with more pronounced hydrophobic properties.

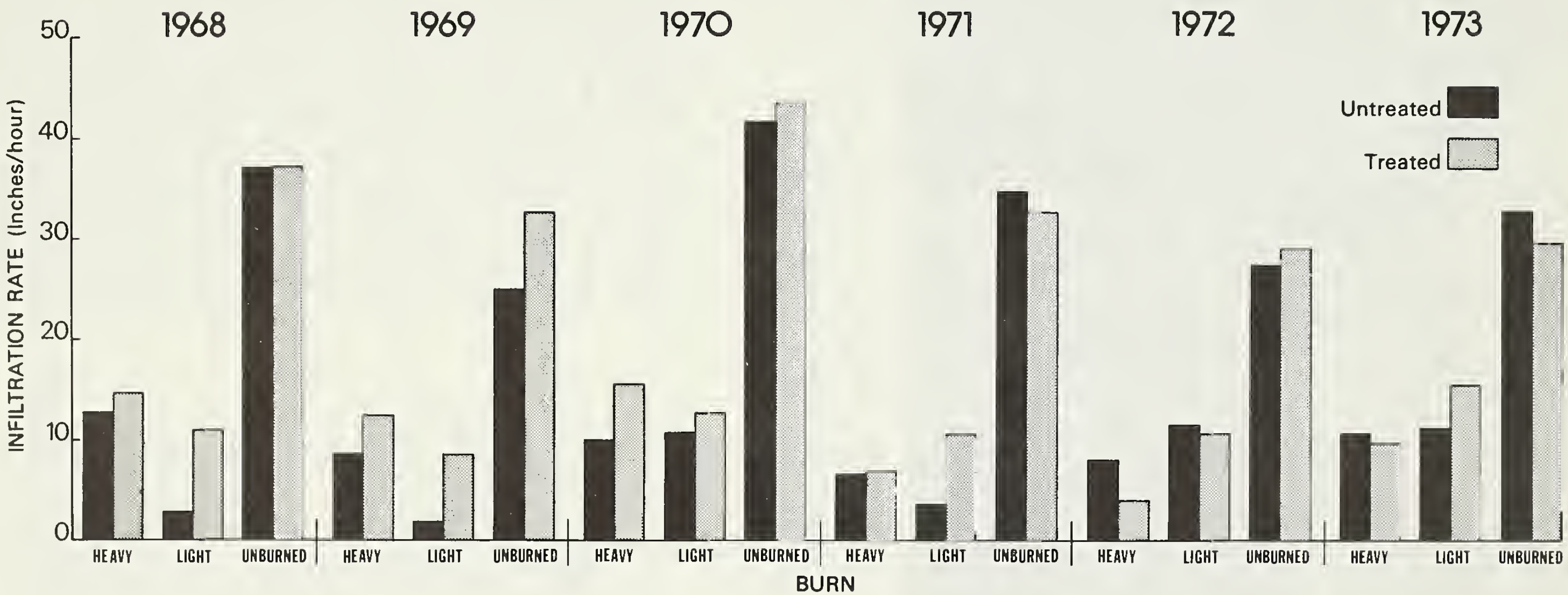

Figure 4.--Mean infiltration rates for untreated plots and plots treated with a wetting agent in heavily burned, lightly burned, and unburned areas for the first 6 years after the fire. Each value represents the mean of the results of six infiltrometer runs.

Figure 5.--Soil wetting patterns in a heavily burned area 2 years after the fire. Photo was taken after 1.4 inches of rain had fallen following a long dry period. Dark soil areas are wet; the light patches are dry.

VEGETATION TRENDS

Before burning, the study site was characterized by relatively sparse vegetation and an extremely depauperate flora. The vegetation plots located in the unburned island contained only 15 vascular plant species. Tree canopy coverage on these plots totaled slightly over 40 percent, and scattered understory plants contributed only about 30-percent coverage (table 6). Revegetation trends on burned plots for 6 years following the fire show a much faster rate of recovery for lightly burned plots compared with those in a heavily burned area. At the end of the 6-year period, lightly burned plots had almost twice as much plant cover as the heavily burned plots (table 6). By 1973, total plant coverage in the lightly burned area was approaching that found in the unburned control.

Table 6 shows that application of the wetting agent in August of 1968 and again in 1969 had no consistent effect on the vegetation. This is contrary to experience elsewhere, in which application of wetting agents to nonwettable soils has resulted in a spectacular increase in plant growth. For example, in a study following a wildfire in the San Dimas Experimental Forest (southern California), plots treated with a wetting agent had four times more grass cover than untreated plots (Osborn et al. 1964). Apparently, in the present study, the nonionic surfactant was leached out of the rooting zone before it could affect plant growth. Most germination and growth occurs early in the summer before the time of the wetting agent application. Since this is an area of summer drought and concentrated winter precipitation, this leaching process would probably be completed before the start of the next growing season. Annual precipitation during the study period averaged about 95 inches (2 413 mm), undoubtedly more than enough to completely leach the surfactant from the upper soil profile.

Table 6--Estimated coverage of common plant species on untreated plots and plots treated with a wetting agent for the first 6 years following the fire. Wetting agent was applied in midsummer in 1968 and 1969; all cover estimates were made in September

Soil condition and species	1968		1969		1970		1971		1972		1973	
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
	Percent											
Unburned plots												
Herbs and grasses												
Lupinus albicaulis	18.8	18.6	21.4	27.3	17.5	24.0	19.3	24.8	19.9	25.0	18.9	21.8
Carex pensylvanica	3.0	4.0	2.5	4.7	2.6	4.3	2.4	2.9	2.4	3.5	2.9	3.4
Stipa occidentalis	2.6	3.8	4.4	5.6	2.7	4.1	2.6	5.2	3.2	4.9	3.4	4.0
Penstemon procerus	2.7	.3	2.5	.2	2.4	.2	2.5	.1	2.5	.1	2.9	.1
Other species	.1	1.6	0	1.3	.1	.8	.3	.7	.1	.8	0	1.1
Total herb layer cover	25.9	26.2	28.0	34.9	23.2	30.5	25.0	33.1	26.5	32.2	23.1	30.0
Shrubs												
Ribes cereum	0	6.0	0	5.0	0	5.0	0	6.0	0	4.5	0	5.0
Total shrub layer cover	0	6.0	0	5.0	0	5.0	0	6.0	0	4.5	0	5.0
Trees												
Pinus contorta	32.1	40.6	30.6	44.6	32.6	44.0	30.1	41.5	32.1	37.1	30.6	36.3
Abies lasiocarpa	10.9	11.8	11.1	12.3	10.7	12.7	13.7	14.3	12.6	9.7	13.6	13.5
Total tree layer cover	38.6	42.2	37.6	44.6	39.1	44.3	38.1	48.1	40.6	43.8	40.1	43.6
Total cover--all layers	64.5	74.4	65.5	84.5	62.3	79.8	63.1	87.2	67.1	80.5	63.2	78.5
Lightly burned plots												
Herbs and grasses												
Carex pensylvanica	15.0	12.7	23.0	22.4	28.0	29.9	33.0	29.1	40.2	28.1	45.9	38.1
Lupinus albicaulis	5.1	4.3	6.6	7.5	7.7	10.8	9.1	9.9	4.0	3.2	5.9	5.6
Stipa occidentalis	.3	.1	1.2	.5	2.1	.6	.8	.3	1.7	1.9	8.0	4.2
Festuca arundinacea	0	0	3.7	4.4	7.6	9.0	3.3	4.2	5.1	3.8	3.6	3.5
Lolium perenne	7.1	8.0	9.6	12.0	6.0	7.9	1.3	3.1	2.0	4.3	1.5	4.3
Other species	.7	.6	.7	.9	.5	.1	.6	.2	1.1	.2	2.3	.5
Total herb layer cover	25.2	22.4	37.5	38.4	44.4	47.5	42.0	38.7	49.2	40.4	59.7	51.6
Shrubs												
Ceanothus velutinus	.3	.3	.2	.3	.3	.7	.6	.7	.9	1.0	.8	1.6
Other species	.2	.1	.1	.1	.1	.2	0	0	0	0	0	0
Total shrub layer cover	.5	.4	.3	.4	.4	.9	.6	.7	.9	1.0	.8	1.6
Trees												
Pinus contorta	.3	.5	.2	.2	.2	.3	.2	.5	.3	1.3	.5	1.3
Total tree layer cover	.3	.5	.2	.2	.2	.3	.2	.5	.3	1.3	.5	1.3
Total cover--all layers	26.0	23.3	38.0	39.0	45.0	48.7	42.8	39.9	50.4	42.7	61.0	54.5
Heavily burned plots												
Herbs and grasses												
Carex pensylvanica	4.4	10.4	10.7	14.6	11.5	16.6	15.4	17.2	17.2	15.3	17.5	15.8
Lupinus albicaulis	3.6	1.2	6.6	3.7	8.9	5.3	9.8	7.3	9.1	6.1	13.4	8.6
Stipa occidentalis	0	0	.5	0	.7	0	.9	0	.8	.1	1.9	Trace
Festuca arundinacea	0	0	.4	1.7	.6	2.9	0	3.4	Trace	2.6	Trace	3.4
Lolium perenne	.7	1.6	.8	2.4	.1	3.0	.2	2.4	Trace	1.8	Trace	2.5
Other species	0	.1	0	.2	0	.2	.2	.3	.4	.1	.8	.2
Total herb layer cover	7.7	13.0	15.2	20.5	16.8	25.2	22.0	28.2	23.5	24.9	29.3	29.6
Shrubs												
Ceanothus velutinus	.3	.2	.3	.2	.3	.3	.2	.3	.2	.5	.1	.4
Total shrub layer cover	.3	.2	.3	.2	.3	.3	.2	.3	.2	.5	.1	.4
Trees												
Pinus contorta	.1	0	0	0	0	0	0	0	0	0	0	0
Total tree layer cover	.1	0	0	0	0	0	0	0	0	0	0	0
Total cover--all layers	8.1	13.2	15.5	20.7	17.1	25.5	22.2	28.5	23.7	25.4	29.4	30.0

The plant species which were important in the early stages of succession after the fire were mostly those present in the preburn stand (table 6). With the exception of snowbrush (*Ceanothus velutinus*), invading species were extremely sparse. Of the species aerially seeded for erosion control, only tall fescue (*Festuca arundinacea*) and perennial ryegrass (*Lolium perenne*) appeared on the burned plots in more than trace amounts. However, even these plants were so scattered that any beneficial soil stabilizing effects were minimal.

DISCUSSION

Hydrophobic soil properties are generally ascribed to organic films which coat soil particles. Although the chemical composition of these coatings is not completely known, they have been variously attributed to products of soil fungi (Bond 1969), products of natural decomposition of plant litter (Bozer et al. 1969), and aliphatic hydrocarbonlike materials produced by heating chaparral litter to temperatures above 300 °C (Savage et al. 1972). The marked resistance to soil wetting observed in our study area appeared to be most directly influenced by lodgepole pine litter. In the unburned portion of the study area, greatest resistance to soil wetting and lowest infiltration rates were observed in those areas where the pine litter was thickest. Apparently most of the resistance to wetting in these unburned soils is confined to the surface inch of mineral soil. As figure 2 indicates, the 0- to 1-inch (0- to 2.5-cm) layer of unburned soil is even more resistant to wetting than that in burned areas. Like other investigators, I can only speculate on the mechanisms responsible for this observed relationship between pine litter and water repellency in the surface soil. Apparently some of the products of needle litter decomposition, when adsorbed on soil particles, bring about marked hydrophobic properties. As DeByle (1973) pointed out in his study in Montana, it is difficult to discern whether the hydrophobic properties are imparted by fungal mycelia, by products of decomposition, or by both.

Pine litter has been found to cause marked water repellency in soils elsewhere in the Western United States. Meeuwig (1971), in his study of infiltration characteristics of granitic soils in the Carson Range of the Sierra Nevada, found continuous layers of water-repellent soil only under pine litter. Other vegetation types (e.g., chaparral) were associated with small patches of water-repellent soils, but not continuous layers.

In the present study, wildfire had pronounced effects on patterns of water repellency in the surface 12 inches (30.5 cm) of soil. Our data indicate that following burning, although the surface inch was less resistant to wetting, wetting resistance was increased below, especially in the 1- to 6-inch (2.5- to 15.2-cm) layers. These results are remarkably similar to the soil wettability patterns observed following fires in the mountains of southern California (DeBano and Krammes 1966, DeBano 1966). There, soil, which before burning was only nonwettable in the surface inch, was found, after burning, to have a wettable 1- to 2-inch (2.5- to 5.1-cm) surface layer underlain by a 2- to 4-inch (5.1- to 10.2-cm) water-repellent layer. Based on these observations and laboratory burning experiments, DeBano (1969b) hypothesized that the downward shift in the water-repellent layer is caused by volatilization of hydrophobic substances during burning and their subsequent condensation in cooler, lower soil layers. Source of these hydrophobic substances was thought to be certain volatile components of chaparral litter. A similar process might also be responsible for causing increased water repellency in

the 2- to 9-inch (5.1- to 22.9-cm) layers for the soils we studied. In the Airstrip Burn area, however, the probable source of volatile hydrophobic substances is pine litter rather than shrub litter.

There has been virtually no information on how long fire-induced decreases in soil wettability persist. Most studies have involved only a single sampling soon after the fire, with very little attention paid to long-term trends in soil wettability. One of the few workers who has addressed this problem is DeByle (1973). In a slash-burned area in Montana, he found evidence for increased water repellency in the surface soil during the first year after burning, but by the second year these changes in wettability were no longer detectable. In our study we found that decreased soil wettability in the 2- to 9-inch (5.1- to 22.9-cm) soil layers continued at a relatively high level for a period of 5 years after burning. However, by the 6th year after the fire, water repellency in the burned soil areas had decreased to the point where values were approaching pre-burn levels.

It is rather difficult to explain the relatively abrupt decrease in resistance to wetting which occurred 6 years after burning. If leaching or microbial degradation processes are responsible for removing hydrophobic coatings from soil particles, decreases in water repellency would be expected to occur more gradually. However, at least in the case of the 2- to 4- and 4- to 6-inch (5.1- to 10.2- and 10.2- to 15.2-cm) soil layers in the heavily burned area, decreases in water repellency were almost negligible until 1973 (fig. 2). In the 1-year period from 1972 to 1973, mean contact angle value decreased 10 degrees. It is also hard to account for the apparent increases in water repellency measured for 1972 samples from burned areas over those collected in 1971. These increases were especially noticeable in the 6- to 9- and 9- to 12-inch (15.2- to 22.9- and 22.9- to 30.5-cm) layers. If there had been a concomitant decrease in repellency in the upper layers, we could perhaps explain it on the basis of the downward leaching of the hydrophobic substance. However, this seems an untenable hypothesis since repellency in upper layers either increased slightly or remained constant during this same period (fig. 2).

Application of a wetting agent had little measurable effect on soil liquid-solid contact angles and, as far as could be determined, no effect on plant cover. There was some indication that the wetting agent may have increased infiltration rates to some extent, but the sample size was too small to adequately test the significance of these results. Since annual precipitation amounts to some 95 inches (2 413 mm) in the study area, it is easy to understand how the material would be quickly leached from the upper soil profile. However, the wetting agent was applied during the dry summer period; and the 1968 and 1969 soil wettability samples were collected and the infiltration tests conducted soon afterward, or before the heavy fall rains began. Even so, measured effects on soil wettability were minimal. However, as pointed out in the section describing revegetation results, the lack of vegetative response is more easily explained because the wetting agent application was carried out after the period of maximum germination and plant growth. Perhaps if the wetting agent had been applied in the early summer, immediately after snowmelt but before plant growth commenced, there might have been a vegetative response. This is, however, purely conjectural, since the upper soil layers should contain more than adequate supplies of available water at this time.

SUMMARY AND CONCLUSIONS

Moderate resistance to wetting may be a common characteristic of sandy soils in the central Oregon Cascades, even in those areas untouched by recent fires. In the Airstrip Burn we found water repellency of soils in an unburned area to be most pronounced in the surface inch of mineral soil. In most instances the unburned soil below 1 inch (2.5 cm) was at least fairly wettable.

For 6 years, measurements after the Airstrip Burn have shown that the fire appears to have caused increased water repellency in burned soils. Although burned soils were slightly more wettable than unburned soils in the surface inch, substantial increases in water repellency were found for the 1- to 6-inch (2.5- to 15.2-cm) soil depths in burned areas. There was some indication that fire-induced increases in resistance to wetting may have extended as deep as 12 inches (30.5 cm). Soils in both heavily and lightly burned areas showed approximately the same reduction in wettability during the first 2 years after the fire. However, during the 3d and 4th years after the fire, recovery toward preburn soil wettability conditions was considerably more rapid in lightly burned than in heavily burned soils.

Liquid-solid contact angle measurements indicated that decreases in soil wettability persisted in the burned areas for 5 years after the fire. By the 6th year, contact angle values for the burned soil samples were approaching those measured in the unburned soil.

The decreased soil wettability in burned areas was borne out by the results of ring infiltrometer tests. Infiltration rates on burned soils were only about one-third as fast as those measured in unburned areas (about 10 versus 30 inches per hour). Although rates in the lightly burned area were even lower than those in the heavily burned area for the first 3 years after the fire, they consistently increased during the final 3 years of measurements. Even so, 6 years after the fire the average infiltration rate for lightly burned plots was only 13 inches per hour, compared with 32 inches per hour for the unburned soil.

Yearly vegetation inventories showed a much faster rate of revegetation on lightly burned than on heavily burned plots. Six years after the fire, vegetation cover totaled 30 percent in the heavily burned area, 58 percent in the lightly burned, and 71 percent in the unburned area. Most of the species in the burned areas were also present before the fire. Grasses and clover which were aerially seeded soon after the burn contributed only negligible amounts of cover.

In August 1968 and again in June 1969, the wetting agent, Aqua-Gro, was applied to half the plots in each of the three conditions (unburned, lightly burned, and heavily burned). We could detect no effect of these applications on plant growth. Effects of the wetting agent on soil wettability, as assessed by contact angle and infiltration rate measurements, were minimal. Apparently nonionic surfactants offer little promise as a practical method for ameliorating the detrimental soil effects of burning, at least in areas receiving sufficient precipitation to leach them from the soil profile.

Following the fire, the Airstrip Burn area contained conspicuous evidences of large-scale overland flow and surface erosion. Heavy fall rains produced numerous examples of rilling and gullying in the burned area. Although this may have been partially caused by the destruction of the discontinuous protective mantle of plants

and litter, the fire-induced water-repellent soils undoubtedly played a major role. Without marked resistance to wetting, these coarse-textured soils would be expected to have such high infiltration rates that surface runoff would be minimal, even in bare soil areas. Fortunately, in this case serious consequences of soil erosion were minimized due to the gentle topography of the study area. However, wildfires in areas with similar soils on steep slopes could lead to very serious erosion problems caused largely by decreased soil wettability. Since the effects of burning on water repellency persist for several years, it is essential that the land manager act immediately to aid soil stabilization as soon as the fire is controlled. In areas of high precipitation, such as the Oregon Cascades, the application of wetting agents apparently does not offer much promise as an effective control measure. Perhaps the most effective treatment would be immediate seeding of well-adapted grass and legume species and liberal application of a nitrogen fertilizer. In addition, refertilization after a year or two might be beneficial.

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